2020 5(1) 1-10 Submission: 2020/05/10, Peer review: 2020/05/20, Accepted: 2020/05/25, Published: 2020/06/30

Kinesiology

Publication state: Japan
ISSN: 2435-0702

Publisher: J-INSTITUTE
Website: http://www.j-institute.jp

Corresponding author
E-mail: cmcho12@kmu.ac.kr

Peer reviewer
E-mail: kinesiology@j-institute.jp

http://dx.doi.org/10.22471/kinesiology.2020.5.1.01

Relationships between the Digit Ratio(2D:4D) and Exercise-Related Physical Fitness Components in Males and Females

Cho Chang-mo

Keimyung University, Daegu, Republic of Korea

Abstract

The relative length of the second and fourth fingers(2D:4D ratio) is a putative biomarker for prenatal testosterone. Low 2D:4D has been known to correlate with morphological, physiological, psychological, and high levels of athletic performance and physical fitness. In this study, it was examined the relationship between the 2D:4D ratio and two important exercise-related fitness components(speed and power) in nonathlete young adults. A total of 108 healthy recreationally active university students(73 male and 35 female, aged 18-20 years) were participated in this study. Body weight and height were measured, and body mass index(BMI) was calculated. The lengths of the second and fourth fingers of the right and left hands were measured, and the 2D:4D ratios were calculated. The difference of the digit ratio between the right and left hands(Dr-l) was also calculated. Speed and power performance were assessed by measuring 100-meter sprint record and handball throwing distance, respectively. Independent t-test was performed to analyze differences between males and females about all variables of physical(height, weight, BMI) and anthropometric(lengths of 2D, 4D, and 2D:4D ratio of both hands, and Dr-l) characteristics. The association between physical and anthropometric characteristics and the speed and power-related performance in each sex(male: speed, power, female: speed only) was determined by the Pearson correlation coefficient. Statistical significance was set at $P < 0.05$. As the main findings of this study, the lengths of the 2D and 4D of males were significantly longer than those of females($P < .001$), while male digit ratios in both hands were significantly lower than females($P < .01$). There was no significant sex difference in Dr-l. In males, significant positive correlations were observed between the handball throwing distances and the body weight($P < .05$) and BMI($P < .01$). In females, there was a significant negative correlation between the length of the fourth digit and 100-meter sprint record($P < .05$). However, the 2D:4D ratio was not correlated with the speed and power performance in males and females. These results suggest that the 2D:4D ratio is not a major parameter in predicting exercise potential in the nonathlete young adult, and more research is needed that focuses on other factors that can affect exercise potential in the population that is similarly affected by prenatal sex hormones.

***[Keywords]* Kinesiology, Finger Length, Digit Ratio, Prenatal Testosterone, Sport Performance**

1. Introduction

Digit ratio is the relative length of the index finger(the second digit, 2D) and the ring finger(the fourth digit, 4D), and in general, 2D:4D ratio for males tends to be lower than for females[1]. It has been known that this digit ratio(or 2D:4D) is influenced by prenatal sex hormones as early as the end of the first trimester, and high prenatal androgens, low prenatal estrogens, or both have been identified as a possible stimulant of a low 2D:4D ratio[2][3]. The

changes of digit ratio influenced by prenatal sex hormones are controlled through Homeobox(Hox) genes which are responsible for controlling the development of musculoskeletal, neurological, and gonadal tissue[4]. As such, the 2D:4D ratio not only indicates the hormonal milieu at the time of development, but can also provide information which has implications for interpreting human behavior and disease. Therefore, there is also important meaning in terms of kinesiology and training related aspects.

Because of the relationships of the 2D:4D ratio with prenatal testosterone concentrations and musculoskeletal development, it was suggested that a low 2D:4D ratio is associated with greater performance in various sports and physical fitness[5][6][7]. Bernet et al.(2010) examined the relationship between the 2D:4D ratio and performance in elite rugby players, and they found high rugby performance correlated with low right hand 2D:4D ratio[8]. Tomkinson and Tomkinson(2017) reported a negative correlation between muscular strength and the 2D:4D ratio in adolescent boys[9]. In relation to the relationship between the digit ratio and the health-related physical fitness components, the digit ratio was shown to have a particularly strong correlation with cardiopulmonary endurance[10][11][12].

In addition, in a study of Mofftt and Swanik(2011), they reported that the 2D:4D ratio of athletes in football and gymnastics, which requires high levels of physical skills, was significantly lower than that of crew(endurance athletes) players and nonathlete[13]. Kociuba et al.(2017) found that the 2D:4D ratio of participants in high-risk sports such as judo or boxing was significantly lower compared to that of aerobic exercise group[14]. Also, according to two different studies of Kilduff et al.(2013a, 2013b), the lower the 2D:4D ratio, the higher the sudden increase in testosterone induced by exercise or by an aggressive video watching were examined[15][16]. The results of these studies indicate that the digit ratio is related not only to physical skills but also to sports interest and motivation.

On the other hand, speed is defined as the magnitude of change in the position of an object between two different points. Power is physically defined as the amount of work accomplished per unit of time, and it is also defined as maximal muscle force exerted by the instantaneous contraction of muscle fibers in exercise physiology aspect. As speed and power are physical fitness components included in the exercise-related physical fitness, these two factors are one of the most important factors that determine how far the shot travels in shot put or how fast someone runs 100-meter sprint[37][38][39]. As mentioned above, the relationship between health-related fitness such as muscle strength and cardiovascular endurance and the 2D:4D ratio has been studied a lot, but the research about the relationship between exercise-related fitness factors and the 2D:4D ratio is relatively scarce.

With this purpose, this research examined the relationships between the digit ratio and the speed and power performance measured by 100-meter sprint record and by handball throwing distance from male and female university students, respectively.

2. Method

2.1. Subjects

A total of 108 healthy men and women(men=73, women = 35) aged 18 to 20 years old were participated in this study. All participants were habitually active in various sports activities. The description of the study's purpose, procedures, and risks was provided prior to participating in this study. This study was conducted in compliance with the guidelines related to research ethics.

2.2. Experimental procedures

Subjects' height was measured to the nearest 0.1 cm using portable stadiometer(Donghwa Science, Korea), which consisted of an anthropometer with a simple headboard. Body weight was measured using Inbody 502(Inbody, Korea) on the barefoot, wearing minimal clothing(T-shirt and trousers). Using the measured height and body weight values, BMI was calculated as weight(kg) divided by height(m) squared.

Finger lengths were measured according to the measurement method described by Manning et al.(1998), and second and forth digits on both left and right hands were measured[1]. The subjects were asked to remove finger ornaments and to keep their hands supine on a flat table surface with the palm facing up and their fingers straight in the same plane. Length of each digit was taken on the ventral aspect of hand from the tip of the finger to the center of the digit crease proximal to the palm. Finger lengths were measured to the nearest 0.01 mm using electronic digital caliper(Wanhanda, China). Length of each finger was measured twice in the same manner, and the average value was used for a statistical analysis. 2D:4D ratio was calculated by dividing the length of the second finger by that of the fourth. Manning et.al.(1998) reported that right 2D:4D ratio showed stronger relationship with testosterone, estrogen, and sperm numbers then did left 2D:4D ratio[1]. It was also reported that right 2D:4D ratio is more sensitive to testosterone/estrogen ratio in the fetus then that of left[17]. Thus, the difference between right 2D:4D and left 2D:4D(Dr-l) has been suggested as an additional indicator for the effect of sex hormones. In this study, Dr-l was also calculated and used to analyze correlations with exercise-related fitness components.

Speed was measured by 100-meter sprint. Subjects performed 100-meter sprint on an outdoor urethane track, and they were asked to run when the wind was as low as possible to minimize the effect of wind. The record of 100-meter sprint was taken to nearest 0.01 second using a laser measuring system(KL sports industry, Korea) that can automatically measure the record through laser sensors installed at the starting and finish lines. Whole body muscle power was measured by handball throwing performance. Handball throwing performance was measured using an international official handball(molten, Japan) with a ball circumference of 58~60 cm and a weight of 425 to 475 g. Subjects took their throw a handball into the legal sector(30°) of the throwing area from inside a marked circle 2-meter in diameter with a stopboard about 10 cm high at the front of the circle. The distance thrown was measured to nearest 0.1 m from the inside of the circumference of the circle to the nearest mark made on the ground by the falling handball using an open reel measuring tape(Colorton measuring tape, Taiwan).

2.3. Statistical analysis

All statistical analyses were analyzed using SPSS version 25.0(IBM, U.S.A), and all data are expressed as mean ± standard deviation(SD). The differences between men and women for the finger lengths, 2D:4D ratios of left and right hands, and Dr-l were analyzed using independent-sample *t*-test. The relationships between the exercise-related fitness components and height, weight, BMI, Dr-l, and the lengths of second and fourth digits, the 2D:4D ratios of both left and right hands were analyzed in each sex by calculating the Pearson correlation coefficients. For all analyses, statistical significance was accepted at $P < 0.05$.

3. Results

3.1. Sex differences in physical and anthropometric characteristics

The subjects' physical and anthropometric characteristics of this study by gender are shown in <Table 1>. Finger length measured from the first measurement was strongly correlated with those measured from the second measurement for the individual subject(left hand 2D: r = 0.991, $P < 0.001$, left hand 4D: r = 0.996, $P < 0.001$, right hand 2D: r = 0.996, $P < 0.001$, right hand 4D:

r = 0.995, $P < 0.001$). There was strong significant correlation between the 2D:4D ratios calculated from the first and second measurement of digit lengths(left hand: r = 0.949, $P < 0.001$, right hand: r = 0.957, $P < 0.001$). The means of left and right hand 2D:4D ratios were also significantly correlated in both gender(male: r = 0.812, $P < 0.001$, female: r = 0.861, $P < 0.001$). These associations mean that there was high test-retest reliability in this data.

In the comparison of the basic components of physical characteristics, men's height, weight, and BMI were significantly higher than those of females. In the comparison of anthropometric characteristics, the lengths of the second and fourth digits on both hands were significantly longer in males than in females. On the other hand, the digit ratios of left and right hands were significantly lower in males. There was no significant difference in the Dr-l between males and females.

Table 1. The differences in physical and anthropometric characteristics between males and females.

Variables	Men(n=73)	Women(n=35)
Age(yrs)	19.07± 0.77	18.86± 0.49
Height(cm)	175.66± 4.58	161.66± 5.06**
Weight(kg)	71.58± 7.41	55.98± 6.38**
BMI(kg/m^2)	23.21± 2.34	21.40± 2.02**
L2D(mm)	72.37± 3.16	66.28± 3.60**
L4D(mm)	75.81± 3.18	68.26± 4.01**
L2D:4D	0.95± 0.03	0.97± 0.03*
R2D(mm)	72.43± 3.15	66.30± 3.75**
R4D(mm)	75.53± 3.19	68.26± 3.95**
R2D:4D	0.96± 0.03	0.97± 0.03*
Dr-l	0.0044± 0.0163	0.0000± 0.0151

Note: Values are presented as mean ± SD. BMI: Body Mass Index., L2D: Left hand second digit, L4D: Left hand fourth digit, L2D:4D: Ratio of left hand second and fourth digit, R2D: Right hand second digit, R4D: Right hand fourth digit, R2D:4D: Ratio of right hand second and fourth digit, Dr-l: Difference between right 2D:4D and left 2D:4D. *p<.01, **p<.001.

3.2. Correlations between physical and anthropometric characteristics and physical performance in males and females

The correlations between physical and anthropometric characteristics and 100-meter sprint and handball throwing performance were calculated from 66 and 49 male subsamples, respectively. <Table 2> depicts the correlations among the variables for each physical performance. All the variables constituting physical and anthropometric characteristics were not significantly correlated with 100-meter sprint performance in males <Table 2>. However, there were significant positive correlations between weight and handball throwing distance(r = 0.328, $P < 0.05$), and BMI and handball throwing distance(r = 0.376, $P < 0.01$) in males <Table 2>. The variables of anthropometric characteristic did not significantly correlate with handball throwing performance <Table 2>.

Table 2. Correlations between physical and anthropometric characteristics and 100-meter sprint and handball throwing performance in males.

Variables	100-meter sprint(n=66)	Handball throwing(n=49)
Height	-0.024	-0.070
Weight	0.038	0.328*
BMI	0.044	0.376**
L2D	-0.052	0.040
L4D	-0.090	0.149

R2D	-0.092	0.027
R4D	-0.064	0.147
L2D:4D	0.062	-0.135
R2D:4D	-0.008	-0.130
Dr-l	-0.147	-0.025

Note: Values are presented as mean ± SD. BMI: Body Mass Index., L2D: Left hand second digit, L4D: Left hand fourth digit, L2D:4D: Ratio of left hand second and fourth digit, R2D: Right hand second digit, R4D: Right hand fourth digit, R2D:4D: Ratio of right hand second and fourth digit, Dr-l: Difference between right 2D:4D and left 2D:4D. *p<.05, **p<.01.

Total 35 women were participated in this study, and 34 cases of 100-meter sprint records were obtained. The result of handball throwing for women was excluded from this study due to lack of cases. Among the female subsamples, there were no significant correlations between the 100-meter sprint performance and either physical characteristics, left hand anthropometric characteristics, and Dr-l <Table 3>. There was a significant negative correlation between the length of right hand fourth digit and 100-meter sprint performance($r = -0.348$, $P < 0.05$) <Table 3>. The other variables on right hand anthropometric characteristics were not significantly correlated with 100-meter sprint performance <Table 3>.

Table 3. Correlations between physical and anthropometric characteristics and 100-meter sprint performance in females.

Variables	100-meter sprint(n=34)
Height	-0.310
Weight	0.104
BMI	0.338
L2D	-0.208
L4D	-0.332
R2D	-0.223
R4D	-0.348*
L2D:4D	0.267
R2D:4D	0.251
Dr-l	-0.027

Note: Values are presented as mean ± SD. BMI: Body Mass Index., L2D: Left hand second digit, L4D: Left hand fourth digit, L2D:4D: Ratio of left hand second and fourth digit, R2D: Right hand second digit, R4D: Right hand fourth digit, R2D:4D: Ratio of right hand second and fourth digit, Dr-l: Difference between right 2D:4D and left 2D:4D. *p<.05.

4. Discussion

In the current study, it was found that males have longer the second and fourth fingers of both hands and have lower 2D:4D values than those of females, and the 2D:4D ratios of both hands were not correlated with the 100-meter sprint and handball throwing performance in both sexes. In addition, in the correlations between the 100-meter sprint performance and physical and anthropometric variables, a significant correlation was found only in females, and the length of fourth finger showed a significant negative correlation with the 100-meter running time.

Hox genes are known to influence on the formation of gonads and the differentiation of the fingers and to control the growth of skeleton and the development of testes or ovaries, which are ultimately responsible for sex differences[18][19][20]. Both men and women are subject to relative effects of male or female hormones in their mother's intrauterine environment. Scientific studies have shown that the female 2D:4D ratio is significantly higher compared to male embryos, and low 2D:4D ratio may be correlate with high prenatal testosterone and low prenatal estrogen concentration[2][21]. In addition, Zheng and Cohn(2011) found the developmental

mechanism underlying sexually dimorphic 2D:4D ratio through a mouse model research[17]. They found that the activity of androgen receptor(AR) and estrogen receptor α(ER-α) is higher in digit 4 than in digit 2 in both sexes, and inactivation of AR causes a higher 2D:4D ratio, whereas inactivation ER-α lead to a lower 2D:4D ratio[17]. In most reported studies, males tend to have a lower 2D:4D ratio compared to females[10][22][23], and these results are also consistent with those of the current study.

Another noteworthy result found in the Zheng and Cohn's study is that the 2D length index(digit length/tibia length) was not affected by a high androgen levels or ER antagonist in females and by a high estradiol or AR antagonist in males, respectively[17]. By contrast, the female 4D length index was increased by androgen enhancing or ER antagonist treatment, and in males, it was decreased by estradiol or AR antagonist treatment[17]. These results suggest that the fourth finger plays a crucial role in the determination of 2D:4D ratio in both sexes, and this result supports the significant correlation result between the women's 100-meter performance and the length of fourth digit found in the current study.

Such as muscle fiber hypertrophy, increased strength, an increase in hematocrit, and power, various factors related to excellence in exercise performance are influenced by testosterone[24][25][26][27]. Therefore, increased prenatal testosterone exposure may be an essential precursor for the success in some sport activities, and it has been suggested that the 2D:4D ratio is a biomarker that determines exercise potential[13]. In fact, many studies have reported that the digit ratio has a significant correlation with exercise performance, physical fitness level, and successful achievement in several sports[10][23][28][29].

However, in the present study, the 2D:4D ratios measured from both hands were not correlated with the speed and power performance in both sexes. This discrepancy between the results of the previous study and the current study seems to be related to the subject's developmental stage, the subject's expertise in physical activity, and the homogeneity of the subject's population. In particular, the difference in the 2D:4D ratio was noticeable between nonathletes and elite athletes. Hsu et al.(2015) compared the 2D:4D ratio of tennis athletes and nonathletes, and they found that the digit ratio of elite tennis athlete group was significantly lower than those of nonathlete group in both males and females[23]. This phenomenon was also observed between elite Greco-Roman wrestlers and nonathlete[30]. In addition to comparisons between athletes and nonathletes, the 2D:4D ratio of prepubertal children who are relatively less affected by sex hormones was found to be significantly related to some athletic performance[7][31]. Lastly, the homogeneity of a group can be considered as a factor that can affect the relationship between the digit ratio and exercise performance. In a study performed by Gallup, White, and Gallup(2007), who studied the relationship between the digit ratio and handgrip strength and sexual behavior from male and female nonathlete college students, the digit ratio of both hands was not related with the handgrip strength performance[32]. Also, in a recent study with adolescent well-trained swimmers, the 2D:4D ratio had no correlation with swimming performance[33], and a similar result was reported in female young adult rowers[10]. All of these results suggest that the higher the homogeneous group, the higher the probability that the digit ratio does not correlate with exercise performance.

As another major finding of the present study, male handball throwing performance was not correlated with all anthropometric variables, but was significantly positively correlated with body weight and BMI, respectively. These results indicate that the higher the weight or BMI, the better the handball throwing performance. As a recent study similar to the results of the current study, Ozen, Atar, and Koc(2019) reported a significant negative correlation between swimming records(50m, 100m, 200m, 400m) and BMI in adolescent swimmers[33]. It was suggested that high BMI levels reflect low testosterone levels with a result of a positive association between the digit ratio and BMI in males[34]. Indeed, Jensen et al.(2004) showed

a negative association between BMI and testosterone levels from the data of 1,558 male subjects[35]. However, a significant decrease in testosterone levels was only observed in the high BMI group(BMI > 25kg/m^2) in this study[36]. In addition, Dongen(2009)[36] reported a significant negative correlation between the digit ratio and BMI in nonathlete males(age of 22.6±2.66) with higher sample size than Fink, Neave, and Manning(2003)[34], and there was an indirect relationship(but not significant) between the digit ratio and body mass in a study of Jurinae et al.(2008)[22]. In the current study, the 2D:4D ratios were not correlated with BMI(left 2D:4D: r = 0.206, *P* = 0.097, right 2D:4D: r = 0.140, *P* = 0.263). Above all, since BMI is a relative measure of body weight to height, high muscle mass or body fat can all contribute to a high BMI, and BMI is particularly inaccurate for people who are very fit or athletic[40]. Thus, it seems more desirable to compare it with detailed body components such as muscle mass and body fat rather than BMI.

In conclusion, the result of this investigation revealed no relationship between the 2D:4D ratio and the speed and power-related performance in males and females. In this respect, this result suggests that the digit ratio is not a major parameter in predicting exercise potential in the nonathlete young adults, regardless of gender. However, in the current investigation, it was also found that there was a positive relationship between female speed performance and their digit length, and male power performance and the body weight and BMI, respectively. Thus, these results also suggest that more research will be required to gain insight into which other factors that can affect exercise potential in the population that is similarly affected by prenatal sex hormone, as well and how these factors could potentially relate with expected associations with digit ratios.

5. References

5.1. Journal articles

[1] Manning JT & Scutt D & Wilson J & Lewis-Jones DI. The Ratio of 2nd to 4th Digit Length: A Predictor of Sperm Numbers and Concentrations of Testosterone, Luteinizing Hormone and Oestrogen. *Human Reproduction*, 13(11), 3000-3004 (1998).

[2] Lutchmaya S & Baron-Cohen S & Raggatt P & Knickmeyer R & Manning JT. 2nd to 4th Digit Ratios, Fetal Testosterone and Estradiol. *Early Human Development*, 77(1-2), 23-28 (2004).

[4] Jamison CS & Meier RJ & Campbell BC. Dermatoglyphic Asymmetry and Testosterone Levels in Normal Males. *American Journal of Physical Anthropology*, 90(2), 185-198 (1993).

[5] Hull MJ & Schranz NK & Manning JT & Tomkinson GR. Relationships between Digit Ratio(2D:4D) and Female Competitive Rowing Performance. *American Journal of Human Biology*, 27(2), 157-163 (2015).

[6] Kilduff LP & Cook CJ & Manning JT. Digit Ratio(2D:4D) and Performance in Male Surfers. *The Journal of Strength & Conditioning Research*, 25(11), 3175-3180 (2011).

[7] Ranson R & Stratton G & Taylor SR. Digit Ratio(2D:4D) and Physical Fitness(Eurofit Test Battery) in School Children. *Early Human Development*, 91(5), 327-331 (2015).

[8] Bennett M & Manning JT & Cook CJ & Kilduff LP. Digit Ratio(2D:4D) and Performance in Elite Rugby Players. *Journal of Sports Sciences*, 28(13), 1415-1421 (2010).

[9] Tomkinson JM & Tomkinson GR. Digit Ratio(2D:4D) and Muscular Strength in Adolescent Boys. *Early Human Development*, 113, 7-9 (2017).

[10] Longman D & Stock JT & Wells JCK. Digit Ratio(2D:4D) and Rowing Ergometer Performance in Males and Females. *American Journal of Physical Anthropology*, 144(3), 337-341 (2011).

[11] Hill R & Simpson B & Manning J & Kilduff L. Right-left Digit Ratio(2D:4D) and Maximal Oxygen Uptake. *Journal of Sports Sciences*, 30(2), 129-134 (2012).

[12] Trivers R & Hopp R & Manning J. A Longitudinal Study of Digit Ratio(2D:4D) and Its Relationships with Adult Running Speed in Jamaicans. *Human Biology*, 85(4), 623-626 (2013).
[13] Moffit DM & Swanik CB. The Association between Athleticism, Prenatal Testosterone, and Finger Length. *The Journal of Strength & Conditioning Research*, 25(4), 1085-1088 (2011).
[14] Kociuba M & Kozieł S & Chakraborty R & Ignasiak Z. Sports Preference and Digit Ratio among Female Students in WrocŁAw, Poland. *Journal of Biosocial Science*, 49(5), 623-633 (2017).
[15] Kilduff LP & Cook CJ & Bennett M & Crewther BT & Bracken RM & Manning JT. Right-left Digit Ratio(2D:4D) Predicts Free Testosterone Levels Associated with a Physical Challenge. *Journal of Sports Sciences*, 31(6), 677-683 (2013).
[16] Kilduff LP & Hopp RN & Cook CJ & Crewther BT & Manning JT. Digit Ratio(2D:4D), Aggression, and Testosterone in Men Exposed to an Aggressive Video Stimulus. *Evolutionary Psychology*, 11(5), 953-964 (2013).
[17] Zheng Z & Cohn MJ. Developmental Basis of Sexually Dimorphic Digit Ratios. *Proceedings of the National Academy of Sciences*, 108(39), 16289-16294 (2011).
[18] Kondo T & Zakany J & Innis JW & Duboule D. Of Fingers, Toes and Penises. *Nature*, 390(6655), 29-29 (1997).
[19] Forest MG. Role of Androgens in Fetal and Pubertal Development. *Hormone Research in Paediatrics*, 18(1-3), 69-83 (1983).
[20] Hiort O. Androgens and Puberty. *Best Practice & Research Clinical Endocrinology & Metabolism*, 16(1), 31-41 (2002).
[21] Malas MA & Dogan S & Evcil EH & Desdicioglu K. Fetal Development of the Hand, Digits and Digit Ratio(2D:4D). *Early Human Development*, 82(7), 469-475 (2006).
[22] Jürimäe T & Voracek M & Jürimäe J & Lätt E & Haljaste K & Saar M & Purge P. Relationships between Finger-length Ratios, Ghrelin, Leptin, IGF Axis, and Sex Steroids in Young Male and Female Swimmers. *European Journal of Applied Physiology*, 104(3), 523-529 (2008).
[23] Hsu CC & Su B & Kan NW & Lai SL & Fong TH & Chi CP & Chang CC & Hsu MC. Elite Collegiate Tennis Athletes have Lower 2D:4D Ratios Than Those of Nonathlete Controls. *The Journal of Strength & Conditioning Research*, 29(3), 822-825 (2015).
[24] Herbst KL & Bhasin S. Testosterone Action on Skeletal Muscle. *Current Opinion in Clinical Nutrition & Metabolic Care*, 7(3), 271-277 (2004).
[25] Manning JT & Trivers IV RL & Thornhill R & Singh D. The 2nd:4th Digit Ratio and Asymmetry of Hand Performance in Jamaican Children. *Laterality: Asymmetries of Body, Brain and Cognition*, 5(2), 121-132 (2000).
[26] Sinha-Hikim I & Roth SM & Lee MI & Bhasin S. Testosterone-induced Muscle Hypertrophy is Associated with an Increase in Satellite Cell Number in Healthy, Young Men. *American Journal of Physiology-Endocrinology and Metabolism*, 285(1), 197-205 (2003).
[27] Sluming VA & Manning JT. Second to Fourth Digit Ratio in Elite Musicians: Evidence for Musical Ability as an Honest Signal of Male Fitness. *Evolution and Human Behavior*, 21(1), 1-9 (2000).
[28] Paul SN & Kato BS & Hunkin JL & Vivekanandan S & Spector TD. The Big Finger: The Second to Fourth Digit Ratio is a Predictor of Sporting Ability in Women. *British Journal of Sports Medicine*, 40(12), 981-983 (2006).
[29] Klapprodt KL & Fitzgerald JS & Short SE & Manning JT & Tomkinson GR. Relationships Between the Digit Ratio(2D:4D) and Game-related Statistics in Professional and Semi-professional Male Basketball Players. *American Journal of Human Biology*, 30(6), e23182 (2018).
[30] Keshavarz M & Bayati M & Farzad B & Dakhili A & Agha-Alinejad H. The Second to Fourth Digit Ratio in Elite and Non-elite Greco-Roman Wrestlers. *Journal of Human Kinetics*, 60(1), 145-151 (2017).
[31] Hsu CC & Fong TH & Chang HM & Su B & Chi CP & Kan NW & Hsu MC. Low Second-to-fourth Digit Ratio has High Explosive Power? A Prepubertal Study. *The Journal of Strength & Conditioning Research*, 32(7), 2091-2095 (2018).

[32] Gallup AC & White DD & Gallup Jr GG. Handgrip Strength Predicts Sexual Behavior, Body Morphology, and Aggression in Male College Students. *Evolution and Human Behavior*, 28(6), 423-429 (2007).
[33] Özen G & Atar Ö & Koç H. Digit Ratio(2D:4D): Relationship with Freestyle Swimming Performance of Adolescent Well-trained Swimmers. *Pedagogics, Psychology, Medical-Biological Problems of Physical Training and Sports*, 23(3), 150-154 (2019).
[34] Fink B & Neave N & Manning JT. Second to Fourth Digit Ratio, Body Mass Index, Waist-to-hip Ratio, and Waist-to-chest Ratio: Their Relationships in Heterosexual Men and Women. *Annals of Human Biology*, 30(6), 728-738 (2003).
[35] Jensen TK & Andersson AM & Jørgensen N & Andersen AG & Carlsen E & Skakkebæk NE. Body Mass Index in Relation to Semen Quality and Reproductive Hormones among 1,558 Danish Men. *Fertility and Sterility*, 82(4), 863-870 (2004).
[36] Van Dongen S. Second to Fourth Digit Ratio in Relation to Age, BMI and Life History in a Population of Young Adults: A Set of Unexpected Results. *Journal of Negative Results*, 6(1), 1-7 (2009).
[37] Kim TH. Comparison of Anaerobic Power according to the Performance Level of Male Middle School Handball Players. *Kinesiology*, 4(2), 42-48 (2019).
[38] Park JS. The Effect of Functional Training on the Physical Strength Factor of Elite Taekwondo Athletes. *Kinesiology*, 4(1), 1-7 (2019).
[39] Kwon TH & Lee MS & Kim TB & Park JM. Effects of High Intensity Yongmudo Training on Maximum Muscle Strength and Yongmudo Performance in the Adult Males. *International Journal of Martial Arts*, 4(2), 14-24 (2019).
[40] Cho CM. Comparison of Validity and Accuracy of Circumference, SKF, and BIA Method in Predicting % Body Fat. *Kinesiology*, 4(2), 14-21 (2019).

5.2. Books

[3] Manning JT. Digit Ratio: A Pointer to Fertility, Behavior, and Health. Rutgers University (2002).

6. Contribution

6.1. Authors contribution

	Initial name	Contribution
Author	CCM	-Set of concepts ☑ -Design ☑ -Getting results ☑ -Analysis ☑ -Make a significant contribution to collection ☑ -Final approval of the paper ☑ -Corresponding ☑ -Play a decisive role in modification ☑ -Significant contributions to concepts, designs, practices, analysis and interpretation of data ☑ -Participants in Drafting and Revising Papers ☑ -Someone who can explain all aspects of the paper ☑

6.2. Authors profile

Author
Cho Chang-mo / Keimyung University Professor
B.A. Keimyung University
M.A. Keimyung University
Ph.D. Keimyung University

Research field
- Effects of Regular Exercise Training and Acute Exhaustive Exercise on Serum SOD Response: The Possibility of Serum SOD as Health-related Indicator, Journal of Advanced Research in Dynamical & Control System, 9(12) (2017).
- Effects of a 4-week Vitamin B6·B9·B12 Supplementation on the Muscle Recovery and Muscular Function Induced by Acute Eccentric Exercise, Kinesiology, 4(1) (2019).

Major career
- 2010~present. Keimyung University, Professor
- 2019~present. International Society for Kinesiology, Research Chairperson